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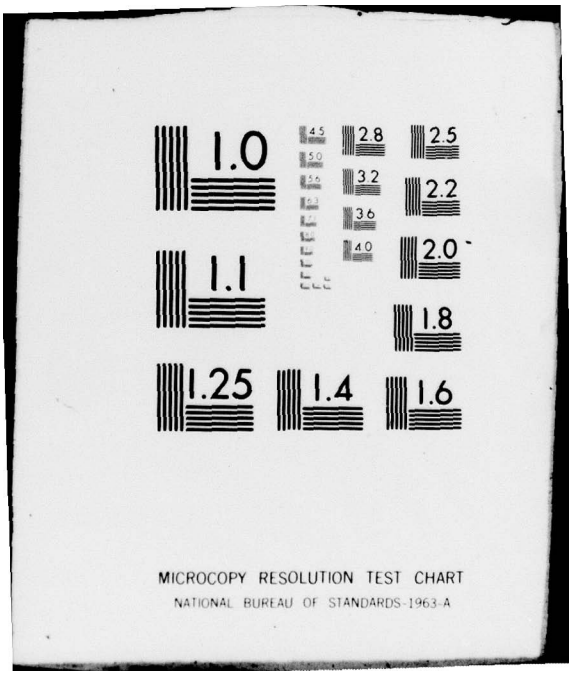
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This document is an annual summary questionnaire response associated with work performed on the project entitled "Structure of Highly Ionized Heavy Ions and Associated Collision Phenomena in the MeV/nucleon Range."



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SUMMARY QUESTIONNAIRE RESPONSE

Principal Investigator: I.A. Sellin
Institution: The University of Tennessee

Contracting Agency: Office of Naval Research
Contract N00014-75-C-0474

Project Title: Structure of Multiply Ionized Heavy Ions and Associated Collision Phenomena

1. Contract Description

Research on highly ionized particles and collision phenomena concerning these and other heavy projectiles is proposed. The primary objective of the research is the study of highly ionized heavy ions and their modes of formation and destruction in collisions with target atoms and molecules. Decay of excited states of these ions by radiative and electron emission processes and the study of energy and angle spectra of ejected electrons are the phenomena most often studied in carrying out these experiments.

2. Scientific Problem

The most important unknown aspect of the proposed experiments is the role of the single step, multiple electron excitation processes in determining the outcome of very violent collisions of highly ionized ions with target atoms and molecules. Multiple electron excitation and rearrangement processes are most probable when the

projectile charge is large and the relative collision velocity is of the order of the internal atomic velocities of participant electrons. Guidance from theory is minimal due to the complete lack of applicability of perturbation theory in such violent encounters. As this area of collisions physics has been very little studied, some of the proposed projects represent long term goals.

Specific near term gools are:

(1) to conduct experimental research concerning electron-ion coincidence spectroscopy of multi-electron, K-ionizing binary collision events for high velocity, high charge state ions in gases;

(2) to perform experimental research concerning correlations between the ejection of forward electrons ("convoy" electrons) in ion-solid collisions by means of studying coincidences between convoy electrons and individual scattered ions;

(3) to perform certain apparatus development work needed to enhance the efficiency of these experiments and to advance the state of art of the coincidence methods used.

3. Scientific and Technical Approach

Principal tools to be used are suitable heavy ion accelerators, electron spectrometers, x-ray, soft x-ray, and extreme ultraviolet spectrometers, heavy particle spectrometers, and a variety of peripheral equipment associated with these devices. In the coincidence measurements noted above, time to amplitude converters

and associated electronic gear, electrostatic electron and magnetic heavy particle analyzers, focusing elements, and particle counting gear will be heavily used. Start events consist of arrival of energy selected electrons at particle multiplier detector cathodes. Stop events consist of charge state selected ions arriving at similar particle multiplier detector cathodes.

4. Progress

We are pleased to report excellent progress in all three areas in which the following goals had been proposed in our proposal of one year ago. It was specifically proposed to: (1) study single and multiple electron loss-to-projectile-centered continuum states subsequent to high velocity collisions of highly charged projectile ions on other atoms by means of an electron spectroscopic technique; (2) study K-Auger spectra and yields in K-shell excited projectiles produced in similar encounters by means of energy analyzing K-Auger electrons emitted near zero degrees with respect to the forward direction; (3) further develop and employ coincidence techniques to study these single and multiple electron loss processes and these related K-Auger spectra and yields in coincidence with the final charge state of the projectile ions.

There has been more complete realization of the specific goals proposed in advance than in any previous contract period.

Specific accomplishments can be succinctly summarized as follows: By measuring forward emitted, projectile K-Auger electrons in coincidence with final scattered ion charge state, we find it possible to quantitatively compare rates for a variety of single and multiple K-ionizing events under single collision conditions. Quantitative tests of an independent electron loss model have been made and failures therein documented. Comparative rates for K-excitation and ionization, and for double K- vs. single K-ejection can be deduced. Exotic processes like coincident K-ejection and bound state capture have been detected and seem amenable to further investigation. Comparative rates for coincident capture of 0,1,2, and 3 electrons into bound states accompanying electron capture to continuum states have been determined for 7-9 au velocity $C^{6+}$, $O^{8+}$ ions in Ar. Estimates based on the high correlations observed lead to the conclusion that traditionally measured cross sections for single and multiple bound state capture have often been inappropriately compared with pure bound state capture theories, ignoring an important unseen channel. Also during the past year, hand-wired, control logic units were built to fully automate the tasks of stepping electron spectrometer voltage at pre-selected intervals (in real time, in voltage, and in integrated projectile number), to register and record singles and coincidence data obtained with standard nuclear modular electronic instrumentation, and to store multiparameter results in pre-selected analyzer memory blocks, for later transfer to magnetic tape/disc units.

5. Publications

List of publications on research accomplished under ONR support, 1 November 1978 to date (present contract year).

Articles in Major Journals and Proceedings:

1. "Coincidence Observations of Strong Correlations Between Bound- and Continuum State Electron Capture by Fast, Highly Ionized Ions in Gases," accepted by Phys. Rev. Letters.

2. "Electron-Ion Coincidence Spectroscopy of Multi-electron, K-ionizing, Binary Collision Events in 7-9 au Velocity $C^{q+}$, $O^{q+}$ Projectiles Traversing Ar," submitted to Phys. Rev. Letters.

3. Invited paper, "Coincidence Spectroscopy of Continuum Electron Transfer in Heavy Ion Collisions," in Abstracts of the Sixth International Seminar on Ion-Atom Collisions, H. Tawara, K. Ozawa, and Y. Nakai, eds. (Japan Atomic Energy Research Institute, Tokai-mura, 1979), p. 2.

4. "Electron Capture Collisions at keV Energies of Boron and Other Multiply Charged Ions with Atoms and Molecules II: Atomic Hydrogen," submitted to Phys. Rev. A.

5. "Many-Electron Aspects of Molecular Promotion in Ion-Atom Collisions: Production of Core-Excited States of Li in $Li^+$ - He Collisions," Phys. Rev. A9, 962 (1979).

6. "Coincidence Experiments Concerning Forward Electron Ejection," in the Proceedings of the Eleventh International Conference on the Physics of Electronic and Atomic Collisions, K. Takayanagi and N. Oda, eds. (Society for Atomic Collision Research, Kyoto, 1979), p. 754.

7. "K-Auger Electrons Observed in Coincidence with Final Projectile Charge State in Ion-Atom Collisions," in the Proceedings of the Eleventh International Conference on the Physics of Electronic and Atomic Collisions, K. Takayanagi and N. Oda, eds. (Society for Atomic Collision Research, Kyoto, 1979), p. 762.

8. "Target Dependences for Continuum Capture Processes in Ion-Atom Collisions," in the Proceedings of the Eleventh International Conference on the Physics of Electronic and Atomic Collisions, K. Takayanagi and N. Oda, eds. (Society for Atomic Collisions Research, Kyoto, 1979), p. 752.

9. "Yield of Convoy Electrons from Solids," to be published in the Proceedings of the Eighth International Conference on Atomic Collisions in Solids, Hamilton, Canada, August, 1979.

10. "Observation of Intense Low Energy Autoionization Lines in the Wings of the Forward Peak from Fast Ion-Atom Collisions," A. Phys. A289, 433 (1979).

11. "Ions," in the McGraw-Hill Annual Yearbook of Science and Technology - 1978, I. Lapides, ed. (McGraw-Hill Book Co., New York, 1979), p. 235.

12. Invited paper, "Electron 'Cusp' Spectroscopy of the Forward Peak in Continuum Electron Capture and Loss in Gases and Solids," Journal de Physique Colloque, Supp. au no. 2, 40, C1-225 (1979).

13. "Oscillator Strength Determinations for $\Delta n = 0$ Transitions in Be-like Ions of the Third Period Elements," Journal de Physique Colloque, Supp. au no. 2, 40, C1-205 (1979).

14. "Coherent Electron Density Distribution Oscillations in Electron Capture by Fast Protons in He," Z. Physik-Short Notes, 258, 321 (1978).

15. "Electron Capture Collisions at keV Energies of Boron and Other Multiply Charged Ions with Atoms and Molecules. I: Ar, $H_2$, and He," submitted to Phys. Rev. A.

16. "Delayed Coincidence Auger Electron Lifetime Measurements," Journal de Physique Colloque, Supp. au. no. 2, 40, C1-221 (1979).

17. "A Systematic Study of the $2s^2 2p^k$-$2s2p^{k+1}$-$2p^{k+2}$ Transitions in Multiply-Charged Cl Ions," Journal de Physique Colloque, Supp. au no. 2, 40, C1-208 (1979).

18. "Radiative Lifetimes of Highly Ionized and Foil-Excited Al," Journal de Physique Colloque, Supp. au no. 2, 40, C1-103 (1979).

19. "Observation of Mixed Parity Electric Dipole Oscillations in Charge-Transfer to the n=2 Hydrogen Levels by Fast Protons in Gases," Phys. Rev. Lett. 42, 570 (1979).

20. Invited paper, "Electron Capture to Continuum States," in the Proceedings of the Fifth Conference on Application of Small Accelerators, IEEE Trans. Nuc. Sci. NS-26, 1078 (1979).

21. Invited paper, "Failure of Single Electron Descriptions of Molecular Orbital Collision Processes," in the Proceedings of the Fifth Conference on Application of Small Accelerators, IEEE Trans. Nuc. Sci. NS-26, 1037 (1979).

22. Invited paper, "A Scanning Proton Microprobe for Trace Element Analysis," in the Proceedings of the Fifth Conference on Application of Small Accelerators, IEEE Trans.Nuc. Sci. N5-26, 1373 (1979).

Other Papers

23. Invited paper, "Multielectron processes in Electron Cusp Coincidence Spectroscopy at High Z and v," to be published in Bull. Am. Phys. Soc., November, 1979.

24. "Coincident Capture of Bound and Continuum Electrons by Fully Stripped C and O Projectiles in $\sim$ 1 MeV/A Single Collisions with Ar Targets," to be published in Bull. Am. Phys. Soc., November, 1979.

25. "Electron-Ion Coincidence Spectroscopy of Multi-electron K-ionizing Processes in Single Collisions of $\sim$ 1 MeV/A $C^{q+}$ and $O^{q+}$ Projectiles with Ar Targets," to be published in Bull. Am. Phys. Soc., November, 1979.

26. "Coincidence Experiments on Electron Loss to Low Lying Projectile-Centered Continuum States of One, Two, and Three Electron Loss Events in High Velocity C+Ar Collisions," Bull. Am. Phys. Soc. 24, 581 (1979).

27. "K-Auger Electrons Observed in Coincidence with Final Projectile Charge State in $\sim$ 1.5 MeV/A Ion-Atom Collisions," Bull. Am. Phys. Soc. 24, 582 (1979).

28. "The Radiative Lifetime of the $4p^5 5p\ ^3/_2[1/2]$ Level in Rb II Using Collinear Fast Ion Beam Laser Spectroscopy,"in Abstracts of the Symposium on Atomic Spectroscopy, Tucson, September, 1979.

29. "Consequences for Parity Violation Experiments of Creation of Mixed-Parity Excited States in H(n=2) Following Single Collisions of Fast $H^+$ gases," Bull. Am. Phys. Soc. 23, 1095 (1978).

30. "Molecular Modulation of H(n=4) Quantum Beats Following Single Foil Excitation of $H^+$, $H_2^+$ and $H_3^+$ Beams," in Bull. Am. Phys. Soc. 23, 1099 (1978).

31. "Search for Correlation Effects Between Multiple Electron Loss to Continuum Events in High Energy $O^{4+}$ - Ar Collisions," Bull. Am. Phys. Soc. 23, 1086 (1978).

32. "Observation of Strong Structure in the Forward Peak from Fast-Projectile Electron Loss," Bull. Am. Phys. Soc. 23, 1086 (1978).

33. "Systematics of Continuum Capture and Loss by Bare and Highly Ionized H, C, O and Si Projectile Ions Traversing He, Ne, and Ar Targets," Bull. Am. Phys. Soc. 23, 1086 (1978).

34. "Electron Capture to Continuum States by Bare Projectile Ions," Bull. Am. Phys. Soc. 23, 1086 (1978).

6. Extenuating Circumstances:

None

7. Unexpended Funds Statement:

No funds are expected to remain unspent at the end of the current contract period.

8,9. List of Personnel Who Have Collaborated in ONR Supported Research

Personnel who have regularly participated in ONR sponsored research

| Name | Title |
|---|---|
| G. D. Alton | Physicist, ORNL |
| S. Berry* | Graduate Research Assistant |
| M. H. Breinig* | Postdoctoral Research Associate |
| C. Bottcher | Physicist, ORNL |
| S. B. Elston* | Assistant Professor, UT |
| J. P. Forester† | Assistant Professor (UT-Chattanooga) |
| G. A. Glass* | Graduate Research Assistant |
| P. M. Griffin | Physicist, ORNL |
| K. O. Groeneveld | Visiting Professor, Fed. Republic of Germany |
| H. H. Haselton | Group Leader (ORNL Fusion Energy Division) |
| H. Hayden | Visiting Associate Professor, U. of Connecticut |
| S. Huldt* | Research Associate |
| R. Laubert | Visiting Professor, E. Carolina Univ. and NYU |
| K. H. Liao | Postdoctoral Research Associate |
| L. I. Liljeby* | Postdoctoral Research Associate |
| J. R. Mowat | Assistant Professor (North Carolina State Univ.) |
| D. J. Pegg* | Associate Professor, UT |
| R. S. Peterson§ | Visiting Assistant Professor (Univ. of Conn.) |
| I. A. Sellin* | Professor, UT |
| S. Schumann | Postdoctoral Research Associate, Fed. Republic of Germany |

*designates current U.T. affiliation
†Ph.D. granted, 1977
§Ph.D. granted, 1976

| Name | Title |
|---|---|
| M. Schauer* | Research Assistant |
| M. Suter* | Postdoctoral Research Associate |
| R. S. Thoe* | Assistant Professor |
| C. T. Vane*†† | Graduate Research Assistant, Postdoctoral Research Assistant |
| J. Wright | Visiting Associate Professor, Univ. of New Hampshire |
| L. Williams | Graduate Research Assistant, UT |

*designates current U.T. affiliation
††Ph.D. granted, 1979

Other Occasional Collaborators who have participated in ONR Supported Work

| Name | Title |
|---|---|
| B. R. Appleton | Physicist, Oak Ridge National Laboratory |
| S. Bashkin | Professor, University of Arizona |
| James Bayfield | Professor, University of Pittsburgh |
| M. D. Brown | Physicist, Naval Surface Weapons Center |
| J. Cecci | Physicist, Princeton Plasma Physics Laboratory |
| D. Crandall | Physicist, Oak Ridge National Laboratory |
| S. Datz | Associate Director, Chemistry Division, Oak Ridge National Laboratory |
| D. Dietrich | Postdoctoral Research Associate, LBL |
| B. L. Donnally | Dean, Lake Forest College |
| H. J. Frischkorn | Graduate Research Assistant, Univ. of Frankfurt/M |
| L. Gardner | Postdoctoral Research Associate, Univ. of Pittsburgh |
| H. Gould | Physicist, LBL |
| B. Johnson | Physicist, BNL |
| K. Jones | Physicist, BNL |
| R. Kauffman | Physicist, Bell Telephone Laboratories |
| H. Kim | Physicist, Oak Ridge National Laboratory |
| T. Kruse | Professor, Rutgers University |
| P. Koch | Assistant Professor, Yale University |
| J. Leavitt | Professor, University of Arizona |
| R. Mann | Postdoctoral Research Associate, Univ. of Frankfurt/M |
| J. R. MacDonald | Professor, Kansas State University |
| R. Marrus | Professor, University of California at Berkeley |
| D. Pisano | Physicist, Brookhaven National Laboratory |

| Name | Title |
|---|---|
| P. Richard | Professor, Kansas State University |
| D. Rosich | Graduate Research Assistant, Univ. of Frankfurt/M |
| R. L. Smick | Postdoctoral Research Associate, Univ. of Tennessee |
| W. W. Smith | Professor, University of Connecticut |
| R. R. Turtle | Postdoctoral Research Associate, Univ. of Tennessee |

10. Other Government-Sponsored Research With Which the Principal Investigator is Affiliated.

A one year grant (first year of a prospective three-year continuing grant) from the National Science Foundation at an annual support level of $95,000 commenced June 1, 1979. Further funding is contingent upon NSF grant action for any period beyond May 30, 1980. This grant provides our largest single source of basic research support in atomic and molecular physics, and together with ONR support represents the only continuing support. A two year instrumentation grant from the National Science Foundation for the development of a position sensitive detector in cylindrical geometry commenced February 1979 at an annual level of $38,000, and will be completed in February 1981 (probably non-renewable). A one-year contract from the Department of Energy for development and interfacing of an atomic hydrogen target to apparatus we use in our electron spectroscopy work commenced August 1, 1979 at a level of $35,000. It is renewable at most once, and will then terminate in either July, 1980 or July, 1981.

Work for ONR is performed within the areas of fast projectile electron loss processes, especially projectile K-ionizing processes. Work for NSF is instead concerned with electron capture collisions and detector development. Work for DOE is concerned with hydrogen target development and use. Overlap occurs only at the level of time-shared equipment and personnel. There is no direct overlap at the research subject matter level.